

**ORGANOPHOTORECEPTOR WITH A CHARGE TRANSPORT MATERIAL  
HAVING AT LEAST THREE LINKED HYDRAZONE GROUPS**

**FIELD OF THE INVENTION**

5           This invention relates to organophotoreceptors suitable for use in electrophotography and, more specifically, to organophotoreceptors having a charge transport material comprising at least three hydrazone groups, bonded together by linking groups and a bridging group.

10                           **BACKGROUND OF THE INVENTION**

          In electrophotography, an organophotoreceptor in the form of a plate, disk, sheet, belt, drum or the like having an electrically insulating photoconductive element on an electrically conductive substrate is imaged by first uniformly electrostatically charging the surface of the photoconductive layer, and then exposing the charged surface to a  
15   pattern of light. The light exposure selectively dissipates the charge in the illuminated areas where light strikes the surface, thereby forming a pattern of charged and uncharged areas, referred to as a latent image. A liquid or solid toner is then provided in the vicinity of the latent image, and toner droplets or particles deposit in the vicinity of either the charged or uncharged areas to create a toned image on the surface of the photoconductive  
20   layer. The resulting toned image can be transferred to a suitable ultimate or intermediate receiving surface, such as paper, or the photoconductive layer can operate as an ultimate receptor for the image. The imaging process can be repeated many times to complete a single image, for example, by overlaying images of distinct color components or effect shadow images, such as overlaying images of distinct colors to form a full color final  
25   image, and/or to reproduce additional images.

          Both single layer and multilayer photoconductive elements have been used. In single layer embodiments, a charge transport material and charge generating material are combined with a polymeric binder and then deposited on the electrically conductive substrate. In multilayer embodiments, the charge transport material and charge  
30   generating material are present in the element in separate layers, each of which can optionally be combined with a polymeric binder, deposited on the electrically conductive

substrate. Two arrangements are possible for a two-layer photoconductive element. In one two-layer arrangement (the "dual layer" arrangement), the charge-generating layer is deposited on the electrically conductive substrate and the charge transport layer is deposited on top of the charge generating layer. In an alternate two-layer arrangement (the "inverted dual layer" arrangement), the order of the charge transport layer and charge generating layer is reversed.

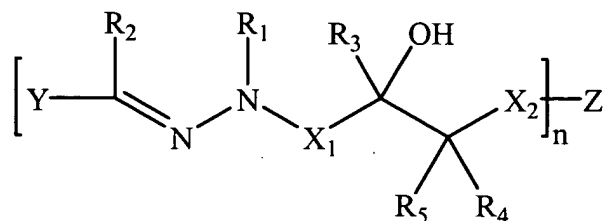
In both the single and multilayer photoconductive elements, the purpose of the charge generating material is to generate charge carriers (i.e., holes and/or electrons) upon exposure to light. The purpose of the charge transport material is to accept at least one type of these charge carriers and transport them through the charge transport layer in order to facilitate discharge of a surface charge on the photoconductive element. The charge transport material can be a charge transport compound, an electron transport compound, or a combination of both. When a charge transport compound is used, the charge transport compound accepts the hole carriers and transports them through the layer with the charge transport compound. When an electron transport compound is used, the electron transport compound accepts the electron carriers and transports them through the layer with the electron transport compound.

### SUMMARY OF THE INVENTION

This invention provides organophotoreceptors having good electrostatic properties such as high  $V_{acc}$  and low  $V_{dis}$ .

In a first aspect, an organophotoreceptor comprises an electrically conductive substrate and a photoconductive element on the electrically conductive substrate, the photoconductive element comprising:

(a) a charge transport material having the formula



where n is an integer between 3 and 6;

R<sub>1</sub> and R<sub>2</sub> are, each independently, H, an alkyl group, an alkenyl group, an aromatic group, or a heterocyclic group;

R<sub>3</sub>, R<sub>4</sub>, and R<sub>5</sub> are, each independently, H, thiol, hydroxyl, carboxyl, an amino group, a halogen, nitro, cyano, an alkyl group, an alkenyl group, an aromatic group, a heterocyclic group, or a part of a ring group;

X<sub>1</sub> and X<sub>2</sub> are, each independently, a linking group, such as a  $-(CH_2)_m-$  group, branched or linear, where m is an integer between 1 and 20, inclusive, and one or more of the methylene groups is optionally replaced by O, S, N, C, B, P, C=O, O=S=O, a heterocyclic group, an aromatic group, urethane, urea, an ester group, an NR<sub>6</sub> group, a CR<sub>7</sub>, or a CR<sub>8</sub>R<sub>9</sub> group where R<sub>6</sub>, R<sub>7</sub>, R<sub>8</sub>, and R<sub>9</sub> are, independently, a bond, H, hydroxyl, thiol, carboxyl, an amino group, an alkyl group, an alkenyl group, a heterocyclic group, an aromatic group, or part of a ring group;

Y comprises an arylamine group; and

Z is a bridging group, such as a  $-(CH_2)_p-$  group, branched or linear, where p is an integer between 1 and 20, inclusive, and at least one of the methylene groups is replaced by O, S, N, C, B, P, C=O, O=S=O, a heterocyclic group, an aromatic group, urethane, urea, an ester group, an NR<sub>10</sub> group, a CR<sub>11</sub>, or a CR<sub>12</sub>R<sub>13</sub> group where R<sub>10</sub>, R<sub>11</sub>, R<sub>12</sub>, and R<sub>13</sub> are, independently, a bond, H, hydroxyl, thiol, carboxyl, an amino group, an alkyl group, an alkenyl group, a heterocyclic group, an aromatic group, or part of a ring group;

(b) a charge generating compound.

The charge transport materials, as described by the above formula, may or may not be symmetrical. Therefore, for example, the linking group X for any given "arm" of the compound within square brackets in the formula above may be the same or different from the linking group X in other "arms" of the compound. Similarly, the R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub>, and R<sub>5</sub> groups for any given "arm" of the compound may be the same or different from the R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub>, and R<sub>5</sub> groups in any other arm. Similarly, the Y group for any given "arm" of the compound may be the same or different from the Y group in any other arm. Furthermore, the bridging group Z itself may or may not be symmetrical with respect to the bonding to the different "arms" of the compound. In addition, the above-described formula for the charge transport compound is intended to cover isomers.

The organophotoreceptor may be provided, for example, in the form of a plate, a flexible belt, a flexible disk, a sheet, a rigid drum, or a sheet around a rigid or compliant drum. In one embodiment, the organophotoreceptor includes: (a) a photoconductive element comprising the charge transport material, the charge generating compound, a second charge transport material, and a polymeric binder; and (b) the electrically conductive substrate.

In a second aspect, the invention features an electrophotographic imaging apparatus that comprises (a) a light imaging component; and (b) the above-described organophotoreceptor oriented to receive light from the light imaging component. The apparatus can further comprise a liquid toner dispenser. The method of electrophotographic imaging with photoreceptors containing the above noted charge transport materials is also described.

In a third aspect, the invention features an electrophotographic imaging process that includes (a) applying an electrical charge to a surface of the above-described organophotoreceptor; (b) imagewise exposing the surface of the organophotoreceptor to radiation to dissipate charge in selected areas and thereby form a pattern of at least relatively charged and uncharged areas on the surface; (c) contacting the surface with a toner, such as a liquid toner that includes a dispersion of colorant particles in an organic liquid, to create a toned image; and (d) transferring the toned image to a substrate.

In a fourth aspect, the invention features a charge transport material having the general formula above.

The invention provides suitable charge transport materials for organophotoreceptors featuring a combination of good mechanical and electrostatic properties. These photoreceptors can be used successfully with liquid toners to produce high quality images. The high quality of the imaging system can be maintained after repeated cycling.

Other features and advantages of the invention will be apparent from the following description of the particular embodiments thereof, and from the claims.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An organophotoreceptor as described herein has an electrically conductive substrate and a photoconductive element comprising a charge generating compound and a charge transport material having at least three hydrazone groups, each bonded,  
5 independently, to an arylamine group. The at least three hydrazone groups are bonded together by linking groups and a bridging group. These charge transport materials have desirable properties as evidenced by their performance in organophotoreceptors for electrophotography. In particular, the charge transport materials of this invention have high charge carrier mobilities and good compatibility with various binder materials, and  
10 possess excellent electrophotographic properties. The organophotoreceptors according to this invention generally have a high photosensitivity, a low residual potential, and a high stability with respect to cycle testing, crystallization, and organophotoreceptor bending and stretching. The organophotoreceptors are particularly useful in laser printers and the like as well as fax machines, photocopiers, scanners and other electronic devices based  
15 on electrophotography. The use of these charge transport materials is described in more detail below in the context of laser printer use, although their application in other devices operating by electrophotography can be generalized from the discussion below.

To produce high quality images, particularly after multiple cycles, it is desirable for the charge transport materials to form a homogeneous solution with the polymeric  
20 binder and remain approximately homogeneously distributed through the organophotoreceptor material during the cycling of the material. In addition, it is desirable to increase the amount of charge that the charge transport material can accept (indicated by a parameter known as the acceptance voltage or " $V_{acc}$ "), and to reduce retention of that charge upon discharge by an imaging source (indicated by a parameter  
25 known as the discharge voltage or " $V_{dis}$ ").

The charge transport materials can be classified as a charge transport compound or an electron transport compound. There are many charge transport compounds and electron transport compounds known in the art for electrophotography. Non-limiting examples of charge transport compounds include, for example, pyrazoline derivatives,  
30 fluorene derivatives, oxadiazole derivatives, stilbene derivatives, enamine derivatives, enamine stilbene derivatives, hydrazone derivatives, carbazole hydrazone derivatives,

(N,N-disubstituted)arylamines such as triaryl amines, polyvinyl carbazole, polyvinyl pyrene, polyacenaphthylene, or multi-hydrazone compounds comprising at least two hydrazone groups and at least two groups selected from the group consisting of (N,N-disubstituted)arylamine such as triphenylamine and heterocycles such as carbazole, julolidine, phenothiazine, phenazine, phenoxazine, phenoxathiin, thiazole, oxazole, isoxazole, dibenzo(1,4)dioxin, thianthrene, imidazole, benzothiazole, benzotriazole, benzoxazole, benzimidazole, quinoline, isoquinoline, quinoxaline, indole, indazole, pyrrole, purine, pyridine, pyridazine, pyrimidine, pyrazine, triazole, oxadiazole, tetrazole, thiadiazole, benzisoxazole, benzisothiazole, dibenzofuran, dibenzothiophene, thiophene, thianaphthene, quinazoline, or cinnoline.

Non-limiting examples of electron transport compounds include, for example, bromoaniline, tetracyanoethylene, tetracyanoquinodimethane, 2,4,7-trinitro-9-fluorenone, 2,4,5,7-tetranitro-9-fluorenone, 2,4,5,7-tetranitroxanthone, 2,4,8-trinitrothioxanthone, 2,6,8-trinitro-indeno[1,2-b]thiophene-4-one, and 1,3,7-trinitrodibenzo thiophene-5,5-dioxide, (2,3-diphenyl-1-indenylidene)malononitrile, 4H-thiopyran-1,1-dioxide and its derivatives such as 4-dicyanomethylene-2,6-diphenyl-4H-thiopyran-1,1-dioxide, 4-dicyanomethylene-2,6-di-m-tolyl-4H-thiopyran-1,1-dioxide, and unsymmetrically substituted 2,6-diaryl-4H-thiopyran-1,1-dioxide such as 4H-1,1-dioxo-2-(p-isopropylphenyl)-6-phenyl-4-(dicyanomethylidene)thiopyran and 4H-1,1-dioxo-2-(p-isopropylphenyl)-6-(2-thienyl)-4-(dicyanomethylidene)thiopyran, derivatives of phospho-2,5-cyclohexadiene, alkoxycarbonyl-9-fluorenylidene)malononitrile derivatives such as (4-n-butoxycarbonyl-9-fluorenylidene)malononitrile, (4-phenethoxycarbonyl-9-fluorenylidene)malononitrile, (4-carbitoxy-9-fluorenylidene)malononitrile, and diethyl(4-n-butoxycarbonyl-2,7-dinitro-9-fluorenylidene)-malonate, anthraquinodimethane derivatives such as 11,11,12,12-tetracyano-2-alkylanthraquinodimethane and 11,11-dicyano-12,12-bis(ethoxycarbonyl)anthraquinodimethane, anthrone derivatives such as 1-chloro-10-[bis(ethoxycarbonyl)methylene]anthrone, 1,8-dichloro-10-[bis(ethoxy carbonyl) methylene]anthrone, 1,8-dihydroxy-10-[bis(ethoxycarbonyl)methylene]anthrone, and 1-cyano-10-[bis(ethoxycarbonyl)methylene]anthrone, 7-nitro-2-aza-9-fluorenylidene-malononitrile, diphenoquinone derivatives, benzoquinone derivatives, naphthoquinone derivatives, quinine derivatives, tetracyanoethylenecyanoethylene, 2,4,8-

trinitro thioxantone, dinitrobenzene derivatives, dinitroanthracene derivatives, dinitroacridine derivatives, nitroanthraquinone derivatives, dinitroanthraquinone derivatives, succinic anhydride, maleic anhydride, dibromo maleic anhydride, pyrene derivatives, carbazole derivatives, hydrazone derivatives, N,N-dialkylaniline derivatives, 5 diphenylamine derivatives, triphenylamine derivatives, triphenylmethane derivatives, tetracyano quinoedimethane, 2,4,5,7-tetranitro-9-fluorenone, 2,4,7-trinitro-9-dicyanomethylene fluorenone, 2,4,5,7-tetranitroxanthone derivatives, and 2,4,8-trinitrothioxanthone derivatives. In some embodiments of interest, the electron transport compound comprises an (alkoxycarbonyl-9-fluorenylidene)malononitrile derivative, such 10 as (4-n-butoxycarbonyl-9-fluorenylidene)malononitrile.

Although there are many charge transport materials available, there is a need for other charge transport materials to meet the various requirements of particular electrophotography applications.

In electrophotography applications, a charge-generating compound within an 15 organophotoreceptor absorbs light to form electron-hole pairs. These electrons and holes can be transported over an appropriate time frame under a large electric field to discharge locally a surface charge that is generating the field. The discharge of the field at a particular location results in a surface charge pattern that essentially matches the pattern drawn with the light. This charge pattern then can be used to guide toner deposition. The 20 charge transport materials described herein are especially effective at transporting charge, and in particular holes from the electron-hole pairs formed by the charge generating compound. In some embodiments, a specific electron transport compound or charge transport compound can also be used along with the charge transport material of this invention.

25 The layer or layers of materials containing the charge generating compound and the charge transport materials are within an organophotoreceptor. To print a two dimensional image using the organophotoreceptor, the organophotoreceptor has a two dimensional surface for forming at least a portion of the image. The imaging process then continues by cycling the organophotoreceptor to complete the formation of the entire 30 image and/or for the processing of subsequent images.

The organophotoreceptor may be provided in the form of a plate, a flexible belt, a disk, a rigid drum, a sheet around a rigid or compliant drum, or the like. The charge transport material can be in the same layer as the charge generating compound and/or in a different layer from the charge generating compound. Additional layers can be used also,  
5 as described further below.

In some embodiments, the organophotoreceptor material comprises, for example: (a) a charge transport layer comprising the charge transport material and a polymeric binder; (b) a charge generating layer comprising the charge generating compound and a polymeric binder; and (c) the electrically conductive substrate. The charge transport  
10 layer may be intermediate between the charge generating layer and the electrically conductive substrate. Alternatively, the charge generating layer may be intermediate between the charge transport layer and the electrically conductive substrate. In further embodiments, the organophotoreceptor material has a single layer with both a charge transport material and a charge generating compound within a polymeric binder.

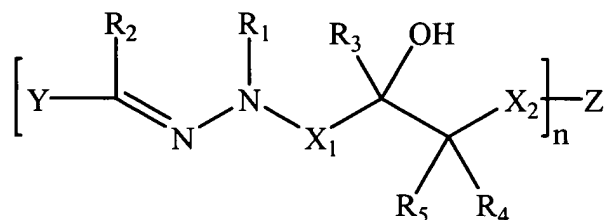
The organophotoreceptors can be incorporated into an electrophotographic imaging apparatus, such as laser printers. In these devices, an image is formed from physical embodiments and converted to a light image that is scanned onto the organophotoreceptor to form a surface latent image. The surface latent image can be used to attract toner onto the surface of the organophotoreceptor, in which the toner  
20 image is the same or the negative of the light image projected onto the organophotoreceptor. The toner can be a liquid toner or a dry toner. The toner is subsequently transferred, from the surface of the organophotoreceptor, to a receiving surface, such as a sheet of paper. After the transfer of the toner, the entire surface is discharged, and the material is ready to cycle again. The imaging apparatus can further  
25 comprise, for example, a plurality of support rollers for transporting a paper receiving medium and/or for movement of the photoreceptor, a light imaging component with suitable optics to form the light image, a light source, such as a laser, a toner source and delivery system and an appropriate control system.

An electrophotographic imaging process generally can comprise (a) applying an  
30 electrical charge to a surface of the above-described organophotoreceptor; (b) imagewise exposing the surface of the organophotoreceptor to radiation to dissipate charge in



selected areas and thereby form a pattern of charged and uncharged areas on the surface;  
 (c) exposing the surface with a toner, such as a liquid toner that includes a dispersion of  
 colorant particles in an organic liquid to create a toner image, to attract toner to the  
 charged or discharged regions of the organophotoreceptor; and (d) transferring the toner  
 5 image to a substrate.

As described herein, an organophotoreceptor comprises a charge transport  
 material having the formula



where n is an integer between 3 and 6;

10  $R_1$  and  $R_2$  are, each independently, H, an alkyl group, an alkenyl group, an aromatic group, or a heterocyclic group;

$R_3$ ,  $R_4$ , and  $R_5$  are, each independently, H, thiol, hydroxyl, carboxyl, an amino group, a halogen, nitro, cyano, an alkyl group, an alkenyl group, an aromatic group, a heterocyclic group, or a part of a ring group;

15  $X_1$  and  $X_2$  are, each independently, a linking group, such as a  $-(CH_2)_m-$  group, branched or linear, where m is an integer between 1 and 20, inclusive, and one or more of the methylene groups is optionally replaced by O, S, N, C, B, P, C=O, O=S=O, a heterocyclic group, an aromatic group, urethane, urea, an ester group, an  $NR_6$  group, a  $CR_7$ , or a  $CR_8R_9$  group where  $R_6$ ,  $R_7$ ,  $R_8$ , and  $R_9$  are, independently, a bond, H,  
 20 hydroxyl, thiol, carboxyl, an amino group, an alkyl group, an alkenyl group, a heterocyclic group, an aromatic group, or part of a ring group;

Y comprises an arylamine group; and

Z is a bridging group, such as a  $-(CH_2)_p-$  group, branched or linear, where p is an integer between 1 and 20, inclusive, and at least one of the methylene groups is replaced  
 25 by O, S, N, C, B, P, C=O, O=S=O, a heterocyclic group, an aromatic group, urethane, urea, an ester group, an  $NR_{10}$  group, a  $CR_{11}$ , or a  $CR_{12}R_{13}$  group where  $R_{10}$ ,  $R_{11}$ ,  $R_{12}$ , and  $R_{13}$  are, independently, a bond, H, hydroxyl, thiol, carboxyl, an amino group, an alkyl group, an alkenyl group, a heterocyclic group, an aromatic group, or part of a ring group.

The charge transport materials of this invention may or may not be symmetrical with respect to the  $n$  "arms" of the compound within the square brackets in the above formula. Therefore, for example, the linking group  $X$  for any given "arm" of the compound may be the same or different from the linking group  $X$  in other "arms" of the compound. Similarly, the  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$ , and  $R_5$  groups for any given "arm" of the compound may be the same or different from the  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$ , and  $R_5$  groups in any other arm. Similarly, the  $Y$  group for any given "arm" of the compound may be the same or different from the  $Y$  group in any other arm. Furthermore, the bridging group  $Z$  itself may or may not be symmetrical with respect to the bonding to the  $n$  "arms." In addition, the above-described formula for the charge transport compound is intended to cover isomers.

The arylamine group includes, but is not limited to, an (N,N-disubstituted)arylamine group (e.g., triarylamine group, alkyldiarylamine group, and dialkylarylamine group), a julolidine group, and a carbazole group.

The heterocyclic group includes any monocyclic or polycyclic (e.g., bicyclic, tricyclic, etc.) ring compound having at least a heteroatom (e.g., O, S, N, P, B, Si, etc.) in the ring.

The aromatic group can be any conjugated system containing  $4n + 2$   $\pi$ -electrons. There are many criteria available for determining aromaticity. A widely employed criterion for the quantitative assessment of aromaticity is the resonance energy. In general, the resonance energy of an aromatic group is greater than 10 KJ/mol. Aromatic groups may be classified as an aromatic heterocyclic group which contains at least a heteroatom in the  $4n + 2$   $\pi$ -electron ring, or as an aryl group which does not contain a heteroatom in the  $4n + 2$   $\pi$ -electron ring. Nonetheless, either the aromatic heterocyclic or the aryl group may have at least one heteroatom in a substituent attached to the  $4n + 2$   $\pi$ -electron ring. Furthermore, either the aromatic heterocyclic or the aryl group may comprise a monocyclic or polycyclic (e.g., bicyclic, tricyclic, etc.) aromatic ring.

Non-limiting examples of the aromatic heterocyclic group are furanyl, thiophenyl, pyrrolyl, indolyl, carbazolyl, benzofuranyl, benzothiophenyl, dibenzofuranyl, dibenzothiophenyl, pyridinyl, pyridazinyl, pyrimidinyl, pyrazinyl, triazinyl, tetrazinyl, petazinyl, quinolinyl, isoquinolinyl, cinnolinyl, phthalazinyl, quinazolinyl, quinoxalinyl,

naphthyridinyl, pteridinyl, acridinyl, phenanthridinyl, phenanthrolinyl, anthyridinyl, purinyl, pteridinyl, alloxazinyl, phenazinyl, phenothiazinyl, phenoxazinyl, phenoxathiinyl, dibenzo(1,4)dioxinyl, thianthrenyl, and a combination thereof. The aromatic heterocyclic group may also include any combination of the above aromatic heterocyclic groups  
5 bonded together either by a bond (as in bicarbazolyl) or by a linking group (as in 1,6-di(10H-10-phenothiazinyl)hexane). The linking group may include an aliphatic group, an aromatic group, a heterocyclic group, or a combination thereof. Furthermore, either an aliphatic group or an aromatic group within a linking group may comprise at least one heteroatom such as O, S, and N.

10 Non-limiting examples of an aryl group are phenyl, naphthyl, benzyl, or tolanyl group, sexiphenylene, phenanthrenyl, anthracenyl, coronenyl, and tolanylphenyl. The aryl group may also include any combination of the above aryl groups bonded together either by a bond (as in biphenyl group) or by a linking group (as in stilbenyl, diphenyl sulfone, an arylamine group). The linking group may include an aliphatic group, an  
15 aromatic group, a heterocyclic group, or a combination thereof. Furthermore, either an aliphatic group or an aromatic group within a linking group may comprise at least one heteroatom such as O, S, and N.

Substitution is liberally allowed on the chemical groups to affect various physical effects on the properties of the compounds, such as mobility, sensitivity, solubility,  
20 stability, and the like, as is known generally in the art. In the description of chemical substituents, there are certain practices common to the art that are reflected in the use of language. The term group indicates that the generically recited chemical entity (e.g., alkyl group, phenyl group, aromatic group, heterocyclic group, arylamine group, etc.) may have any substituent thereon which is consistent with the bond structure of that  
25 group. For example, where the term 'alkyl group' is used, that term would not only include unsubstituted linear, branched and cyclic alkyls, such as methyl, ethyl, isopropyl, tert-butyl, cyclohexyl, dodecyl and the like, but also such structures with substituents having heteroatom such as 3-ethoxylpropyl, 4-(N-ethylamino)butyl, 3-hydroxypentyl, 2-thiolhexyl, 1,2,3-tribromopropyl, and the like. However, as is consistent with such  
30 nomenclature, no substitution would be included within the term that would alter the fundamental bond structure of the underlying group. For example, where a phenyl group

is recited, substitution such as 1-aminophenyl, 2,4-dihydroxyphenyl, 1,3,5-trithiophenyl, 1,3,5-trimethoxyphenyl and the like would be acceptable within the terminology, while substitution of 1,1,2,2,3,3-hexamethylphenyl would not be acceptable as that substitution would require the ring bond structure of the phenyl group to be altered to a non-aromatic form. When referring to an arylamine group, the substituent cited will include any substitution that does not substantively alter the fundamental bond structure, such as aromaticity or conjugation, of the arylamine group. Where the term moiety is used, such as alkyl moiety or phenyl moiety, that terminology indicates that the chemical material is not substituted. Where the term alkyl moiety is used, that term represents only an unsubstituted alkyl hydrocarbon group, whether branched, straight chain, or cyclic.

#### Organophotoreceptors

The organophotoreceptor may be, for example, in the form of a plate, a sheet, a flexible belt, a disk, a rigid drum, or a sheet around a rigid or compliant drum, with flexible belts and rigid drums generally being used in commercial embodiments. The organophotoreceptor may comprise, for example, an electrically conductive substrate and on the electrically conductive substrate a photoconductive element in the form of one or more layers. The photoconductive element can comprise both a charge transport material and a charge generating compound in a polymeric binder, which may or may not be in the same layer, as well as a second charge transport material such as a charge transport compound or an electron transport compound in some embodiments. For example, the charge transport material and the charge generating compound can be in a single layer. In other embodiments, however, the photoconductive element comprises a bilayer construction featuring a charge generating layer and a separate charge transport layer. The charge generating layer may be located intermediate between the electrically conductive substrate and the charge transport layer. Alternatively, the photoconductive element may have a structure in which the charge transport layer is intermediate between the electrically conductive substrate and the charge generating layer.

The electrically conductive substrate may be flexible, for example in the form of a flexible web or a belt, or inflexible, for example in the form of a drum. A drum can have a hollow cylindrical structure that provides for attachment of the drum to a drive that

rotates the drum during the imaging process. Typically, a flexible electrically conductive substrate comprises an electrically insulating substrate and a thin layer of electrically conductive material onto which the photoconductive material is applied.

The electrically insulating substrate may be paper or a film forming polymer such as polyester (e.g., polyethylene terephthalate or polyethylene naphthalate), polyimide, polysulfone, polypropylene, nylon, polyester, polycarbonate, polyvinyl resin, polyvinyl fluoride, polystyrene and the like. Specific examples of polymers for supporting substrates included, for example, polyethersulfone (Stabar<sup>TM</sup> S-100, available from ICI), polyvinyl fluoride (Tedlar<sup>®</sup>, available from E.I. DuPont de Nemours & Company), polybisphenol-A polycarbonate (Makrofol<sup>TM</sup>, available from Mobay Chemical Company) and amorphous polyethylene terephthalate (Melinar<sup>TM</sup>, available from ICI Americas, Inc.). The electrically conductive materials may be graphite, dispersed carbon black, iodine, conductive polymers such as polypyrroles and Calgon<sup>®</sup> conductive polymer 261 (commercially available from Calgon Corporation, Inc., Pittsburgh, Pa.), metals such as aluminum, titanium, chromium, brass, gold, copper, palladium, nickel, or stainless steel, or metal oxide such as tin oxide or indium oxide. In embodiments of particular interest, the electrically conductive material is aluminum. Generally, the photoconductor substrate has a thickness adequate to provide the required mechanical stability. For example, flexible web substrates generally have a thickness from about 0.01 to about 1 mm, while drum substrates generally have a thickness from about 0.5 mm to about 2 mm.

The charge generating compound is a material that is capable of absorbing light to generate charge carriers, such as a dye or pigment. Non-limiting examples of suitable charge generating compounds include, for example, metal-free phthalocyanines (e.g., ELA 8034 metal-free phthalocyanine available from H.W. Sands, Inc. or Sanyo Color Works, Ltd., CGM-X01), metal phthalocyanines such as titanium phthalocyanine, copper phthalocyanine, oxytitanium phthalocyanine (also referred to as titanyl oxyphthalocyanine, and including any crystalline phase or mixtures of crystalline phases that can act as a charge generating compound), hydroxygallium phthalocyanine, squarylium dyes and pigments, hydroxy-substituted squarylium pigments, perylimides, polynuclear quinones available from Allied Chemical Corporation under the trade name

Indofast<sup>®</sup> Double Scarlet, Indofast<sup>®</sup> Violet Lake B, Indofast<sup>®</sup> Brilliant Scarlet and Indofast<sup>®</sup> Orange, quinacridones available from DuPont under the trade name Monastral<sup>™</sup> Red, Monastral<sup>™</sup> Violet and Monastral<sup>™</sup> Red Y, naphthalene 1,4,5,8-tetracarboxylic acid derived pigments including the perinones, tetrabenzoporphyrins and tetranaphthaloporphyrins, indigo- and thioindigo dyes, benzothioxanthene-derivatives, perylene 3,4,9,10-tetracarboxylic acid derived pigments, polyazo-pigments including bisazo-, trisazo- and tetrakisazo-pigments, polymethine dyes, dyes containing quinazoline groups, tertiary amines, amorphous selenium, selenium alloys such as selenium-tellurium, selenium-tellurium-arsenic and selenium-arsenic, cadmium sulphoselenide, cadmium selenide, cadmium sulphide, and mixtures thereof. For some embodiments, the charge generating compound comprises oxytitanium phthalocyanine (e.g., any phase thereof), hydroxygallium phthalocyanine or a combination thereof.

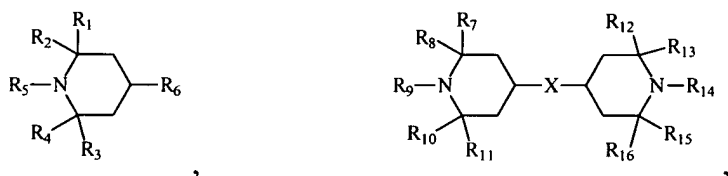
The photoconductive layer of this invention may optionally contain a second charge transport material which may be a charge transport compound, an electron transport compound, or a combination of both. Generally, any charge transport compound or electron transport compound known in the art can be used as the second charge transport material.

An electron transport compound and a UV light stabilizer can have a synergistic relationship for providing desired electron flow within the photoconductor. The presence of the UV light stabilizers alters the electron transport properties of the electron transport compounds to improve the electron transporting properties of the composite. UV light stabilizers can be ultraviolet light absorbers or ultraviolet light inhibitors that trap free radicals.

UV light absorbers can absorb ultraviolet radiation and dissipate it as heat. UV light inhibitors are thought to trap free radicals generated by the ultraviolet light and after trapping of the free radicals, subsequently to regenerate active stabilizer moieties with energy dissipation. In view of the synergistic relationship of the UV stabilizers with electron transport compounds, the particular advantages of the UV stabilizers may not be their UV stabilizing abilities, although the UV stabilizing ability may be further advantageous in reducing degradation of the organophotoreceptor over time. The improved synergistic performance of organophotoreceptors with layers comprising both

an electron transport compound and a UV stabilizer are described further in copending U.S. Patent Application Serial Number 10/425,333 filed on April 28, 2003 to Zhu, entitled "Organophotoreceptor With A Light Stabilizer," incorporated herein by reference.

Non-limiting examples of suitable light stabilizer include, for example, hindered trialkylamines such as Tinuvin 144 and Tinuvin 292 (from Ciba Specialty Chemicals, Terrytown, NY), hindered alkoxydialkylamines such as Tinuvin 123 (from Ciba Specialty Chemicals), benzotriazoles such as Tinuvan 328, Tinuvin 900 and Tinuvin 928 (from Ciba Specialty Chemicals), benzophenones such as Sanduvor 3041 (from Clariant Corp., Charlotte, N.C.), nickel compounds such as Arbestab (from Robinson Brothers Ltd, West Midlands, Great Britain), salicylates, cyanocinnamates, benzylidene malonates, benzoates, oxanilides such as Sanduvor VSU (from Clariant Corp., Charlotte, N.C.), triazines such as Cyagard UV-1164 (from Cytec Industries Inc., N.J.), polymeric sterically hindered amines such as Luchem (from Atochem North America, Buffalo, NY). In some embodiments, the light stabilizer is selected from the group consisting of hindered trialkylamines having the following formula:



where  $R_1, R_2, R_3, R_4, R_6, R_7, R_8, R_{10}, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}$  are, independently, hydrogen, alkyl group, or ester, or ether group; and  $R_5, R_9$ , and  $R_{14}$  are, independently, alkyl group; and X is a linking group selected from the group consisting of  $-O-CO-(CH_2)_m-CO-O-$  where m is between 2 to 20.

The binder generally is capable of dispersing or dissolving the charge transport material (in the case of the charge transport layer or a single layer construction), the charge generating compound (in the case of the charge generating layer or a single layer construction) and/or an electron transport compound for appropriate embodiments. Examples of suitable binders for both the charge generating layer and charge transport layer generally include, for example, polystyrene-co-butadiene, polystyrene-co-acrylonitrile, modified acrylic polymers, polyvinyl acetate, styrene-alkyd resins, soya-alkyl resins, polyvinylchloride, polyvinylidene chloride, polyacrylonitrile, polycarbonates, polyacrylic acid, polyacrylates, polymethacrylates, styrene polymers, polyvinyl butyral,

alkyd resins, polyamides, polyurethanes, polyesters, polysulfones, polyethers, polyketones, phenoxy resins, epoxy resins, silicone resins, polysiloxanes, poly(hydroxyether) resins, polyhydroxystyrene resins, novolak, poly(phenylglycidyl ether)-co-dicyclopentadiene, copolymers of monomers used in the above-mentioned  
5 polymers, and combinations thereof. Specific suitable binders include, for example, polyvinyl butyral, polycarbonate, and polyester. Non-limiting examples of polyvinyl butyral include BX-1 and BX-5 from Sekisui Chemical Co. Ltd., Japan. Non-limiting examples of suitable polycarbonate include polycarbonate A which is derived from bisphenol-A (e.g. Iupilon-A from Mitsubishi Engineering Plastics, or Lexan 145 from  
10 General Electric); polycarbonate Z which is derived from cyclohexylidene bisphenol (e.g. Iupilon-Z from Mitsubishi Engineering Plastics Corp, White Plain, New York); and polycarbonate C which is derived from methylbisphenol A (from Mitsubishi Chemical Corporation). Non-limiting examples of suitable polyester binders include ortho-polyethylene terephthalate (e.g. OPET TR-4 from Kanebo Ltd., Yamaguchi, Japan).

15        Suitable optional additives for any one or more of the layers include, for example, antioxidants, coupling agents, dispersing agents, curing agents, surfactants, and combinations thereof.

The photoconductive element overall typically has a thickness from about 10 microns to about 45 microns. In the dual layer embodiments having a separate charge  
20 generating layer and a separate charge transport layer, charge generation layer generally has a thickness from about 0.5 microns to about 2 microns, and the charge transport layer has a thickness from about 5 microns to about 35 microns. In embodiments in which the charge transport material and the charge generating compound are in the same layer, the layer with the charge generating compound and the charge transport composition  
25 generally has a thickness from about 7 microns to about 30 microns. In embodiments with a distinct electron transport layer, the electron transport layer has an average thickness from about 0.5 microns to about 10 microns and in further embodiments from about 1 micron to about 3 microns. In general, an electron transport overcoat layer can increase mechanical abrasion resistance, increases resistance to carrier liquid and  
30 atmospheric moisture, and decreases degradation of the photoreceptor by corona gases.



A person of ordinary skill in the art will recognize that additional ranges of thickness within the explicit ranges above are contemplated and are within the present disclosure.

Generally, for the organophotoreceptors described herein, the charge generation compound is in an amount from about 0.5 to about 25 weight percent, in further  
5 embodiments in an amount from about 1 to about 15 weight percent, and in other embodiments in an amount from about 2 to about 10 weight percent, based on the weight of the photoconductive layer. The charge transport material is in an amount from about 10 to about 80 weight percent, based on the weight of the photoconductive layer, in further embodiments in an amount from about 35 to about 60 weight percent, and in other  
10 embodiments from about 45 to about 55 weight percent, based on the weight of the photoconductive layer. The optional second charge transport material, when present, can be in an amount of at least about 2 weight percent, in other embodiments from about 2.5 to about 25 weight percent, based on the weight of the photoconductive layer, and in further embodiments in an amount from about 4 to about 20 weight percent, based on the  
15 weight of the photoconductive layer. The binder is in an amount from about 15 to about 80 weight percent, based on the weight of the photoconductive layer, and in further embodiments in an amount from about 20 to about 75 weight percent, based on the weight of the photoconductive layer. A person of ordinary skill in the art will recognize that additional ranges within the explicit ranges of compositions are contemplated and are  
20 within the present disclosure.

For the dual layer embodiments with a separate charge generating layer and a charge transport layer, the charge generation layer generally comprises a binder in an amount from about 10 to about 90 weight percent, in further embodiments from about 15 to about 80 weight percent and in some embodiments in an amount from about 20 to  
25 about 75 weight percent, based on the weight of the charge generation layer. The optional charge transport material in the charge generating layer, if present, generally can be in an amount of at least about 2.5 weight percent, in further embodiments from about 4 to about 30 weight percent and in other embodiments in an amount from about 10 to about 25 weight percent, based on the weight of the charge generating layer. The charge  
30 transport layer generally comprises a binder in an amount from about 20 weight percent to about 70 weight percent and in further embodiments in an amount from about 30

weight percent to about 50 weight percent. A person of ordinary skill in the art will recognize that additional ranges of binder concentrations for the dual layer embodiments within the explicit ranges above are contemplated and are within the present disclosure.

For the embodiments with a single layer having a charge generating compound  
5 and a charge transport material, the photoconductive layer generally comprises a binder, a charge transport material, and a charge generation compound. The charge generation compound can be in an amount from about 0.05 to about 25 weight percent and in further embodiment in an amount from about 2 to about 15 weight percent, based on the weight of the photoconductive layer. The charge transport material can be in an amount from  
10 about 10 to about 80 weight percent, in other embodiments from about 25 to about 65 weight percent, in additional embodiments from about 30 to about 60 weight percent and in further embodiments in an amount from about 35 to about 55 weight percent, based on the weight of the photoconductive layer, with the remainder of the photoconductive layer comprising the binder, and optional additives, such as any conventional additives. A  
15 single layer with a charge transport composition and a charge generating compound generally comprises a binder in an amount from about 10 weight percent to about 75 weight percent, in other embodiments from about 20 weight percent to about 60 weight percent, and in further embodiments from about 25 weight percent to about 50 weight percent. Optionally, the layer with the charge generating compound and the charge  
20 transport material may comprise a second charge transport material. The optional second charge transport material, if present, generally can be in an amount of at least about 2.5 weight percent, in further embodiments from about 4 to about 30 weight percent and in other embodiments in an amount from about 10 to about 25 weight percent, based on the weight of the photoconductive layer. A person of ordinary skill in the art will recognize  
25 that additional composition ranges within the explicit compositions ranges for the layers above are contemplated and are within the present disclosure.

In general, any layer with an electron transport layer can advantageously further include a UV light stabilizer. In particular, the electron transport layer generally can comprise an electron transport compound, a binder, and an optional UV light stabilizer.  
30 An overcoat layer comprising an electron transport compound is described further in copending U.S. Patent Application Serial No. 10/396,536 to Zhu et al. entitled,

“Organophotoreceptor With An Electron Transport Layer,” incorporated herein by reference. For example, an electron transport compound as described above may be used in the release layer of the photoconductors described herein. The electron transport compound in an electron transport layer can be in an amount from about 10 to about 50  
5 weight percent, and in other embodiments in an amount from about 20 to about 40 weight percent, based on the weight of the electron transport layer. A person of ordinary skill in the art will recognize that additional ranges of compositions within the explicit ranges are contemplated and are within the present disclosure.

The UV light stabilizer, if present, in any one or more appropriate layers of the  
10 photoconductor generally is in an amount from about 0.5 to about 25 weight percent and in some embodiments in an amount from about 1 to about 10 weight percent, based on the weight of the particular layer. A person of ordinary skill in the art will recognize that additional ranges of compositions within the explicit ranges are contemplated and are within the present disclosure.

For example, the photoconductive layer may be formed by dispersing or  
15 dissolving the components, such as one or more of a charge generating compound, the charge transport material of this invention, a second charge transport material such as a charge transport compound or an electron transport compound, a UV light stabilizer, and a polymeric binder in organic solvent, coating the dispersion and/or solution on the  
20 respective underlying layer and drying the coating. In particular, the components can be dispersed by high shear homogenization, ball-milling, attritor milling, high energy bead (sand) milling or other size reduction processes or mixing means known in the art for effecting particle size reduction in forming a dispersion.

The photoreceptor may optionally have one or more additional layers as well. An  
25 additional layer can be, for example, a sub-layer or an overcoat layer, such as a barrier layer, a release layer, a protective layer, or an adhesive layer. A release layer or a protective layer may form the uppermost layer of the photoconductor element. A barrier layer may be sandwiched between the release layer and the photoconductive element or used to overcoat the photoconductive element. The barrier layer provides protection  
30 from abrasion to the underlayers. An adhesive layer locates and improves the adhesion between a photoconductive element, a barrier layer and a release layer, or any

combination thereof. A sub-layer is a charge blocking layer and locates between the electrically conductive substrate and the photoconductive element. The sub-layer may also improve the adhesion between the electrically conductive substrate and the photoconductive element.

5           Suitable barrier layers include, for example, coatings such as crosslinkable siloxanol-colloidal silica coating and hydroxylated silsesquioxane-colloidal silica coating, and organic binders such as polyvinyl alcohol, methyl vinyl ether/maleic anhydride copolymer, casein, polyvinyl pyrrolidone, polyacrylic acid, gelatin, starch, polyurethanes, polyimides, polyesters, polyamides, polyvinyl acetate, polyvinyl chloride, polyvinylidene  
10 chloride, polycarbonates, polyvinyl butyral, polyvinyl acetoacetal, polyvinyl formal, polyacrylonitrile, polymethyl methacrylate, polyacrylates, polyvinyl carbazoles, copolymers of monomers used in the above-mentioned polymers, vinyl chloride/vinyl acetate/vinyl alcohol terpolymers, vinyl chloride/vinyl acetate/maleic acid terpolymers, ethylene/vinyl acetate copolymers, vinyl chloride/vinylidene chloride copolymers,  
15 cellulose polymers, and mixtures thereof. The above barrier layer polymers optionally may contain small inorganic particles such as fumed silica, silica, titania, alumina, zirconia, or a combination thereof. Barrier layers are described further in U.S. Patent 6,001,522 to Woo et al., entitled "Barrier Layer For Photoconductor Elements Comprising An Organic Polymer And Silica," incorporated herein by reference. The  
20 release layer topcoat may comprise any release layer composition known in the art. In some embodiments, the release layer is a fluorinated polymer, siloxane polymer, fluorosilicone polymer, silane, polyethylene, polypropylene, polyacrylate, or a combination thereof. The release layers can comprise crosslinked polymers.

          The release layer may comprise, for example, any release layer composition  
25 known in the art. In some embodiments, the release layer comprises a fluorinated polymer, siloxane polymer, fluorosilicone polymer, polysilane, polyethylene, polypropylene, polyacrylate, poly(methyl methacrylate-co-methacrylic acid), urethane resins, urethane-epoxy resins, acrylated-urethane resins, urethane-acrylic resins, or a combination thereof. In further embodiments, the release layers comprise crosslinked  
30 polymers.

The protective layer can protect the organophotoreceptor from chemical and mechanical degradation. The protective layer may comprise any protective layer composition known in the art. In some embodiments, the protective layer is a fluorinated polymer, siloxane polymer, fluorosilicone polymer, polysilane, polyethylene, polypropylene, polyacrylate, poly(methyl methacrylate-co-methacrylic acid), urethane resins, urethane-epoxy resins, acrylated-urethane resins, urethane-acrylic resins, or a combination thereof. In some embodiments of particular interest, the release layers are crosslinked polymers.

An overcoat layer may comprise an electron transport compound as described further in copending U.S. Patent Application Serial No. 10/396,536, filed on March 25, 2003 to Zhu et al. entitled, "Organoreceptor With An Electron Transport Layer," incorporated herein by reference. For example, an electron transport compound, as described above, may be used in the release layer of this invention. The electron transport compound in the overcoat layer can be in an amount from about 2 to about 50 weight percent, and in other embodiments in an amount from about 10 to about 40 weight percent, based on the weight of the release layer. A person of ordinary skill in the art will recognize that additional ranges of composition within the explicit ranges are contemplated and are within the present disclosure.

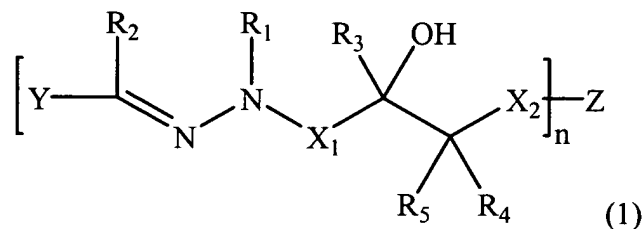
Generally, adhesive layers comprise a film forming polymer, such as polyester, polyvinylbutyral, polyvinylpyrrolidone, polyurethane, polymethyl methacrylate, poly(hydroxy amino ether) and the like. Barrier and adhesive layers are described further in U.S. Patent 6,180,305 to Ackley et al., entitled "Organic Photoreceptors for Liquid Electrophotography," incorporated herein by reference.

Sub-layers can comprise, for example, polyvinylbutyral, organosilanes, hydrolyzable silanes, epoxy resins, polyesters, polyamides, polyurethanes, and the like. In some embodiments, the sub-layer has a dry thickness between about 20 Angstroms and about 2,000 Angstroms. Sublayers containing metal oxide conductive particles can be between about 1 and about 25 microns thick. A person of ordinary skill in the art will recognize that additional ranges of compositions and thickness within the explicit ranges are contemplated and are within the present disclosure.

The charge transport materials as described herein, and photoreceptors including these compounds, are suitable for use in an imaging process with either dry or liquid toner development. For example, any dry toners and liquid toners known in the art may be used in the process and the apparatus of this invention. Liquid toner development can be desirable because it offers the advantages of providing higher resolution images and requiring lower energy for image fixing compared to dry toners. Examples of suitable liquid toners are known in the art. Liquid toners generally comprise toner particles dispersed in a carrier liquid. The toner particles can comprise a colorant/pigment, a resin binder, and/or a charge director. In some embodiments of liquid toner, a resin to pigment ratio can be from 1:1 to 10:1, and in other embodiments, from 4:1 to 8:1. Liquid toners are described further in Published U.S. Patent Applications 2002/0128349, entitled "Liquid Inks Comprising A Stable Organosol," 2002/0086916, entitled "Liquid Inks Comprising Treated Colorant Particles," and 2002/0197552, entitled "Phase Change Developer For Liquid Electrophotography," all three of which are incorporated herein by reference.

#### Charge Transport Material

As described herein, an organophotoreceptor comprises a charge transport material having the formula



where n is an integer between 3 and 6;

R<sub>1</sub> and R<sub>2</sub> are, each independently, H, an alkyl group, an alkenyl group, an aromatic group, or a heterocyclic group;

R<sub>3</sub>, R<sub>4</sub>, and R<sub>5</sub> are, each independently, H, thiol, hydroxyl, carboxyl, an amino group, a halogen, nitro, cyano, an alkyl group, an alkenyl group, an aromatic group, a heterocyclic group, or a part of a ring group;

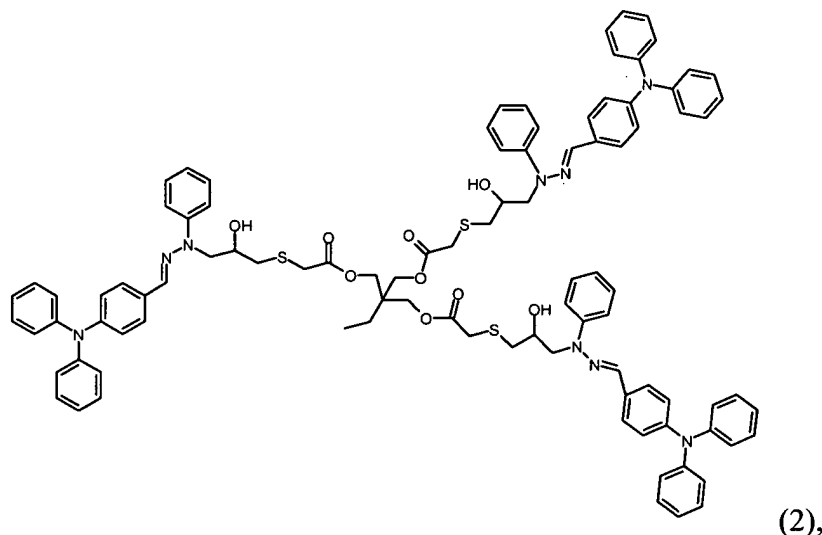
X<sub>1</sub> and X<sub>2</sub> are, each independently, a linking group, such as a -(CH<sub>2</sub>)<sub>m</sub>- group, branched or linear, where m is an integer between 1 and 20, inclusive, and one or more of

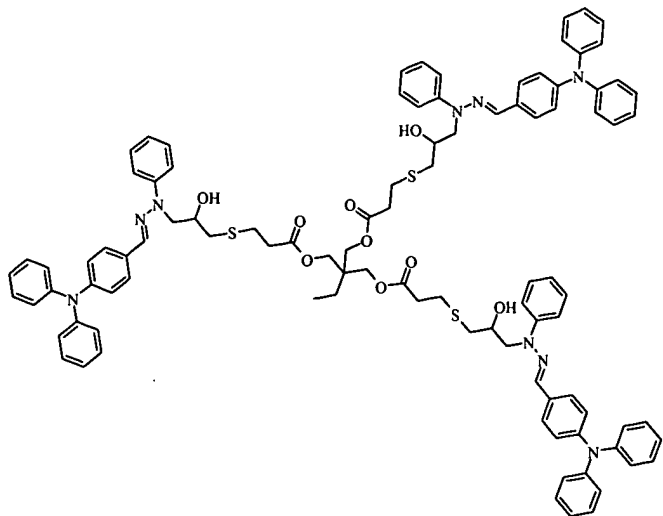
the methylene groups is optionally replaced by O, S, N, C, B, P, C=O, O=S=O, a heterocyclic group, an aromatic group, urethane, urea, an ester group, an NR<sub>6</sub> group, a CR<sub>7</sub>, or a CR<sub>8</sub>R<sub>9</sub> group where R<sub>6</sub>, R<sub>7</sub>, R<sub>8</sub>, and R<sub>9</sub> are, independently, a bond, H, hydroxyl, thiol, carboxyl, an amino group, an alkyl group, an alkenyl group, a  
 5 heterocyclic group, an aromatic group, or part of a ring group;

Y comprises an arylamine group; and

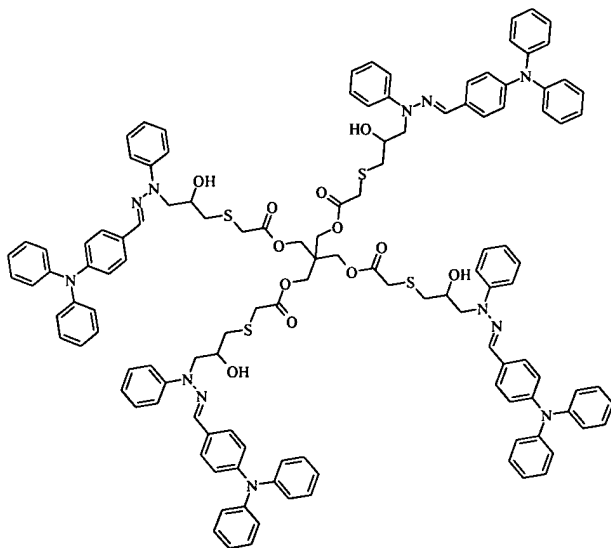
Z is a bridging group, such as a  $-(CH_2)_p-$  group, branched or linear, where p is an integer between 1 and 20, inclusive, and at least one of the methylene groups is replaced by O, S, N, C, B, P, C=O, O=S=O, a heterocyclic group, an aromatic group, urethane,  
 10 urea, an ester group, an NR<sub>10</sub> group, a CR<sub>11</sub>, or a CR<sub>12</sub>R<sub>13</sub> group where R<sub>10</sub>, R<sub>11</sub>, R<sub>12</sub>, and R<sub>13</sub> are, independently, a bond, H, hydroxyl, thiol, carboxyl, an amino group, an alkyl group, an alkenyl group, a heterocyclic group, an aromatic group, or part of a ring group.

Specific, non-limiting examples of suitable charge transport materials within the general Formula (1) above have the following structures:





(3), and



(4).

5

### Synthesis Of Charge Transport Materials

The synthesis of the charge transport materials of this invention can be prepared by the following multi-step synthetic procedure, although other suitable procedures can be used by a person of ordinary skill in the art based on the disclosure herein. In general, the n "arms" branching from the bridging group Z can either be synthesized prior to joining the arms to Z, the arms can be modified or constructed around bridging group Z, the bridging group Z can be assembled from components after joining the components to the arms or a portion thereof, or some combination of these can be performed. As



described in the example synthesis below, the bridging group Z is bonded to the n linking groups X<sub>2</sub> prior to joining the resulting compound with the remainder of the arms.

To form one of the arms, a suitable first step is the acylation of an arylamine compound, such as carbazole, triphenylamine, or julolidine, to form the corresponding arylamine compound having an aldehyde or a keto group, such as 4-(diphenylamino)benzaldehyde, 9-ethyl-3-carbazolecarboxaldehyde, or julolidine aldehyde. Acylation reactions, including some typical Friedel-Crafts acylations, of aromatic compounds are described in Herbert House, "Modern Synthetic Reactions," 2<sup>nd</sup> Edition, Menlo Park, 1972, pp. 797-816, incorporated herein by reference. Non-limiting examples of suitable acylation agents are phosphorous oxychloride (POCl<sub>3</sub>) in N,N-dimethylformamide (DMF), and a mixture of an acid anhydride (e.g. acetic anhydride) or acid chloride (e.g. acetyl chloride) and a Lewis acid, (e.g. zinc chloride, stannic chloride, and aluminum chloride). More than one arylamine compound having an aldehyde or a keto group may be prepared if an unsymmetrical charge transport material is desired.

The second step is the reaction between an (N-substituted)hydrazine and the arylamine compound having an aldehyde or a keto group in a molar ratio of about 1:1 to form the corresponding (N-substituted)hydrazone of the arylamine compound by refluxing the reactants in a solvent, such as tetrahydrofuran, for two hours. More than one (N-substituted)hydrazone may be prepared if an unsymmetrical charge transport material is desired.

The third step is the epoxidation of the (N-substituted)hydrazone obtained in the second step by reacting the (N-substituted)hydrazone with an organic halide comprising an epoxy group under alkaline catalysis to form the corresponding (N-substituted)hydrazone having an epoxy group. Non-limiting examples of suitable organic halide comprising an epoxy group for this invention are epihalohydrins, such as epichlorohydrin. The organic halide comprising an epoxy group can also be prepared by the epoxidation reaction of the corresponding organic halide having an olefin group, as described in Carey et al., "Advanced Organic Chemistry, Part B: Reactions and Synthesis," New York, 1983, pp. 494-498, incorporated herein by reference. The organic halide having an olefin group can also be prepared by the Wittig reaction between a suitable organic halide having an aldehyde or keto group and a suitable Wittig reagent, as

described in Carey et al., "Advanced Organic Chemistry, Part B: Reactions and Synthesis," New York, 1983, pp. 69-77, incorporated herein by reference. More than one (N-substituted)hydrazone having an epoxy group may be prepared if an unsymmetrical charge transport material is desired.

5           The next step is the reaction of the corresponding (N-substituted)hydrazone having an epoxy group with a multi-functional compound having at least three functional groups, each of which may react with an epoxy group. The function groups of the multi-functional compound may be the same or different. Non-limiting examples of an appropriate functional group are hydroxyl, thiol, carboxyl, and an amino group. Non-  
10   limiting examples of such linking compound are trimethylolpropane, pentaerythritol, trimethylolpropane tris(2-mercaptoacetate), trimethylolpropane tris(3-mercaptopropionate), and pentaerythritol tetrakis(2-mercaptoacetate). If a symmetrical charge transport material is desired, the molar ratio of the linking compound to the (N-substituted)hydrazone having an epoxy group is n:1, depending on the value of n in the  
15   corresponding Formula (1) for the desired charge transport material. The reaction may be carried out in a solvent, such as tetrahydrofuran, in the presence of triethylamine, which functions as a catalyst. The reaction mixture may be refluxed until one of the reactants disappears. At the end of the reaction, both the solvent and triethylamine are distilled off and the desired product is purified by column chromatography. If an unsymmetrical  
20   charge transport material is desired, two or more different (N-substituted)hydrazones having an epoxy group may be used. Each (N-substituted)hydrazone having an epoxy group will react, one at a time, with the linking compound in a molar ratio of 1:1 under the condition described above.

25           The invention will now be described further by way of the following examples.

## EXAMPLES

### Example 1 - Synthesis Of A Precursor Compound

30           This example describes the synthesis and characterization of the precursor compound, 4-(diphenylamino)benzaldehyde-N-2,3-epoxypropyl-N-phenylhydrazone, that is used in the synthesis of charge transport materials, as described in Example 2.

Preparation of 4-(Diphenylamino)benzaldehyde-N-2,3-epoxypropyl-N-phenylhydrazone

Phenylhydrazine (0.1 mole, commercially available from Aldrich, Milwaukee, WI) and 4-(Diphenylamino) benzaldehyde (0.1 mole, available from Fluka, Buchs SG, Switzerland) were dissolved in 100 ml of isopropanol in a 250 ml 3-neck round bottom  
5 flask equipped with reflux condenser and mechanical stirrer. The solution was refluxed for 2 hours. Thin layer chromatography indicated the disappearance of the starting materials. At the end of the reaction, the mixture was cooled to room temperature. The 4-(diphenylamino) benzaldehyde phenylhydrazone crystals that formed upon standing were filtered off, washed with isopropanol and dried in vacuum oven at 50 °C for 6 hours.

10 A mixture of 4-(diphenylamino) benzaldehyde phenylhydrazone (3.6 g, 0.01 mole), 85% powdered potassium hydroxide (2.0 g, 0.03 mole) and anhydrous potassium carbonate in 25 ml of epichlorohydrin was stirred vigorously at 55-60 °C for 1.5-2 hours. The course of the reaction was monitored using thin layer chromatography on silica gel 60 F254 plates (from Merck, Whitehouse Station, NJ) using 1:4 v/v mixture of acetone  
15 and hexane as eluant. After termination of the reaction, the mixture was cooled to room temperature, diluted with ether, and washed with water until the wash water had a neutral pH. The organic layer was dried over anhydrous magnesium sulfate, treated with activated charcoal, and filtered. Ether was removed and the residue was recrystallized from a 1:1 volume per volume mixture of toluene and isopropanol. The crystals that  
20 formed upon standing were filtered off and washed with isopropanol to give 3.0 g of product (71.4% yield) with a melting point of 141-142.5 °C. The product was recrystallized for a second time from a 1:1 mixture of toluene and isopropanol. The product was characterized with <sup>1</sup>H-NMR in CDCl<sub>3</sub> (250 MHz instrument) with peaks observed at the following values (δ, ppm): 7.65-6.98 (m, 19H), 6.93 (t, J= 7.2Hz, 1H),  
25 4.35 (dd , 1H), 3.99 (dd , 1H), 3.26 (m , 1H), 2.84 (dd , 1H), and 2.62 (dd , 1H). An elemental analysis yielded the following results in weight percent: C 80.02%, H 6.31%, N 9.91%, comparing with calculated values for C<sub>28</sub>H<sub>25</sub>N<sub>3</sub>O of: C 80.16%, H 6.01%, and N 10.02%.

Example 2 - Synthesis And Characterization Charge Transport Materials

This example described the synthesis and characterization of Compounds (2)-(4) in which the numbers refer to formula numbers above. The characterization involves chemical characterization of the compounds, and the electrostatic characterization of materials formed with the compounds is presented in subsequent examples.

Compound (2)

A mixture of 4-(diphenylamino)benzaldehyde N-2,3-epoxypropyl-N-phenylhydrazone (5.0 g, 11.92 mmol), trimethylolpropane tris(2-mercaptoacetate) (1.06 g, 2.98 mmol, available from Aldrich), and triethylamine (0.8 ml, available from Aldrich) was refluxed in 20 ml of anhydrous tetrahydrofuran under argon for 12 hours. After evaporation of the solvent, the residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich) using a mixture of acetone and hexane in a ratio of 1:4 by volume as the eluant. The fractions containing the product were collected, and the solvent was evaporated to obtain an oily residue. The oily residue was dissolved in toluene to form a 20% solution. The solution was poured with intensive stirring into a tenfold excess of *n*-hexane to yield a solid of Compound (2). Compound (2) was collected by filtration and dried. The yield was 3.4 g (71 %). The product was characterized with an IR spectrum [with KBr windows,  $\nu$  (cm<sup>-1</sup>): 3455 (OH), 3072, 3029, 3007 (CH<sub>arom</sub>), 2967, 2924 (CH<sub>aliph</sub>); 1731 (COO); 828 (*p*-substituted benzene); and 753, 656 (mono substituted benzene). An elemental analysis yielded the following results in weight percent: C 71.28%; H 5.51%; N 7.65%, comparing with calculated values for C<sub>96</sub>H<sub>95</sub>N<sub>9</sub>S<sub>3</sub>O<sub>9</sub> of: C 71.39%; H 5.93%; N 7.81%.

Compound (3)

A mixture of 4-(diphenylamino)benzaldehyde N-2,3-epoxypropyl-N-phenylhydrazone (5.0 g, 11.92 mmol, synthesized as described in Example 1), trimethylolpropane tris(3-mercaptopropionate) (1.19 g, 2.98 mmol, available from Aldrich), and triethylamine (0.8 ml, available from Aldrich) was refluxed in 20 ml of anhydrous tetrahydrofuran under argon for 12 hours. After evaporation of the solvent, the residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich) using a mixture of acetone and hexane in a ratio of 1:4 by volume as the

eluant. The fractions containing the product were collected, and the solvent was evaporated to obtain an oily residue. The oily residue was dissolved in toluene to form a 20% solution. The solution was poured with intensive stirring into a tenfold excess of *n*-hexane to yield a solid of Compound (3). Compound (3) was collected by filtration and dried. The yield was 3.5 g (71 %). The product was characterized with an IR spectrum [with KBr windows,  $\nu$  (cm<sup>-1</sup>): 3445 (OH), 3077, 3033 (CH<sub>arom</sub>), 2960, 2895 (CH<sub>aliph</sub>); 1738 (COO); 827 (*p*-substituted benzene); and 752, 695 (mono substituted benzene). The product was characterized with <sup>1</sup>H-NMR in CDCl<sub>3</sub> (250 MHz instrument) with peaks observed at the following values ( $\delta$ , ppm): 7.80-6.88 (m, 60H, Ar); 4.26-3.84 (m, 15H, CH<sub>2</sub>CH, COOCH<sub>2</sub>); 3.39 (m, 3H, OH); 2.92-2.42 (m, 18H, CH<sub>2</sub>SCH<sub>2</sub>CH<sub>2</sub>); 1.40 (m, 2H, CH<sub>2</sub>CH<sub>3</sub>); and 0.85 (t, 3H, CH<sub>2</sub>CH<sub>3</sub>). An elemental analysis yielded the following results in weight percent: C 71.68%; H 6.11%; N 7.55%, comparing with calculated values for C<sub>99</sub>H<sub>101</sub>N<sub>9</sub>S<sub>3</sub>O<sub>9</sub> of: C 71.76%; H 6.14%; N 7.61%.

#### Compound (4)

A mixture of 4-(diphenylamino)benzaldehyde N-2,3-epoxypropyl-N-phenylhydrazone (5.0 g, 11.92 mmol, synthesized as described in Example 1), pentaerythritol tetrakis(2-mercaptoacetate) (1.03 g, 2.38 mmol, available from Aldrich) and triethylamine (0.8 ml, available from Aldrich) was refluxed in 20 ml of anhydrous tetrahydrofuran under argon for 12 hours. After the evaporation of the solvent, the residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich) using a mixture of acetone and hexane in a ratio of 1:4 by volume as the eluant. The fractions containing the product were collected, and the solvent was evaporated to obtain an oily residue. The oily residue was dissolved in toluene to form a 20% solution. The solution was poured with intensive stirring into a tenfold excess of *n*-hexane to yield a solid of Compound (4). Compound (4) was collected by filtration and dried. The yield was 3.8 g (73 %). The product was characterized with an IR spectrum [with KBr windows,  $\nu$  (cm<sup>-1</sup>): 3407 (OH, br), 3060, 3035 (CH<sub>arom</sub>), 2956, 2923 (CH<sub>aliph</sub>); and 1733 (COO). An elemental analysis yielded the following results in weight percent: C 71.06%; H 5.61%; N 7.85%, comparing with calculated values for C<sub>125</sub>H<sub>120</sub>N<sub>12</sub>S<sub>4</sub>O<sub>12</sub> of: C 71.13%; H 5.73%; N 7.96%.

Example 3 - Charge Mobility Measurements

This example describes the measurement of charge mobility for samples formed with one of the three charge transport materials described in Example 2.

5    Sample 1

A mixture of 0.1 g of Compound (2) and 0.1 g of polyvinylbutyral (S-LEC B BX-1, commercially obtained from Sekisui) was dissolved in 2 ml of tetrahydrofuran. The solution was coated with a dip roller on a polyester film with a conductive aluminum layer. After the coating was dried for 1 hour at 80 °C, a clear 10 µm thick layer was  
10    formed. Table 1 presents the measured hole mobility of the sample.

Sample 2

Sample 2 was prepared and tested similarly as Sample 1, except that no polyvinylbutyral binder was used.

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Sample 3

Sample 3 was prepared and tested similarly as Sample 1, except that Compound (3) replaced Compound (2)

20    Sample 4

Sample 4 was prepared and tested similarly as Sample 2, except that Compound (3) replaced Compound (2).

Sample 5

25    Sample 5 was prepared and tested similarly as Sample 1, except that Compound (4) replaced Compound (2).

Sample 6

Sample 6 was prepared and tested similarly as Sample 5, except that a  
30    polycarbonate Z binder replaced the polyvinylbutyral binder.

Mobility Measurements

Each sample was corona charged positively up to a surface potential  $U$  and illuminated with 2 ns long nitrogen laser light pulse. The hole mobility  $\mu$  was determined as described in Kalade et al., "Investigation of charge carrier transfer in electrophotographic layers of chalcogenide glasses," Proceeding IPCS 1994: The Physics and Chemistry of Imaging Systems, Rochester, NY, pp. 747-752, incorporated herein by reference. The hole mobility measurement was repeated with changes to the charging regime to charge the sample to different  $U$  values, which corresponded to a different electric field strength,  $E$ , inside the layer. This dependence on electric field strength was approximated by the formula

$$\mu = \mu_0 e^{\alpha \sqrt{E}}$$

Here  $E$  is electric field strength,  $\mu_0$  is the zero field mobility and  $\alpha$  is Pool-Frenkel parameter. Table 1 lists the mobility characterizing parameters  $\mu_0$  and  $\alpha$  values and the mobility value at the  $6.4 \times 10^5$  V/cm field strength as determined from these measurements.

Table 1

Sample	$\mu_0$ (cm <sup>2</sup> /V·s)	$\mu$ (cm <sup>2</sup> /V·s) at $6.4 \cdot 10^5$ V/cm	$\alpha$ (cm/V) <sup>0.5</sup>	Ionization Potential (eV)
Sample 1 [Compound (2)]	$5.6 \cdot 10^{-8}$	$1.4 \cdot 10^{-6}$	0.0041	5.45
Sample 2 [Compound (2)]	$9 \cdot 10^{-7}$	$5.4 \cdot 10^{-5}$	0.0051	
Sample 3 [Compound (3)]	$6 \cdot 10^{-8}$	$1 \cdot 10^{-6}$	0.0036	5.45
Sample 4 [Compound (3)]	$8 \cdot 10^{-7}$	$3 \cdot 10^{-5}$	0.0046	
Sample 5 [Compound (4)]	$1.2 \cdot 10^{-8}$	$7.7 \cdot 10^{-7}$	0.0052	5.36
Sample 6 [Compound (4)]	$1 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	0.0037	

Example 4 - Ionization Potential Measurements

This example describes the measurement of the ionization potential for the three charge transport materials described in Example 2.

To perform the ionization potential measurements, a thin layer of charge transport material with about 0.5  $\mu\text{m}$  thickness was coated from a solution of 2 mg of charge transport material in 0.2 ml of tetrahydrofuran onto a 20  $\text{cm}^2$  substrate surface. The substrate was polyester film with an aluminum layer over a methylcellulose sublayer of about 0.4  $\mu\text{m}$  thickness.

Ionization potential was measured as described in Grigalevicius et al., "3,6-Di(N-diphenylamino)-9-phenylcarbazole and its methyl-substituted derivative as novel hole-transporting amorphous molecular materials," *Synthetic Metals* **128** (2002), p. 127-131, incorporated herein by reference. In particular, each sample was illuminated with monochromatic light from the quartz monochromator with a deuterium lamp source. The power of the incident light beam was  $2\cdot 5\cdot 10^{-8}$  W. A negative voltage of  $-300$  V was supplied to the sample substrate. A counter-electrode with the  $4.5\times 15$   $\text{mm}^2$  slit for illumination was placed at 8 mm distance from the sample surface. The counter-electrode was connected to the input of a BK2-16 type electrometer, working in the open input regime, for the photocurrent measurement. A  $10^{-15} - 10^{-12}$  amp photocurrent was flowing in the circuit under illumination. The photocurrent,  $I$ , was strongly dependent on the incident light photon energy  $h\nu$ . The  $I^{0.5}=f(h\nu)$  dependence was plotted. Usually, the dependence of the square root of photocurrent on incident light quanta energy is well described by linear relationship near the threshold (see references "Ionization Potential of Organic Pigment Film by Atmospheric Photoelectron Emission Analysis," *Electrophotography*, 28, Nr. 4, p. 364 (1989) by E. Miyamoto, Y. Yamaguchi, and M. Yokoyama; and "Photoemission in Solids," *Topics in Applied Physics*, **26**, 1-103 (1978) by M. Cordona and L. Ley, both of which are incorporated herein by reference). The linear part of this dependence was extrapolated to the  $h\nu$  axis, and the  $I_p$  value was determined as the photon energy at the interception point. The ionization potential measurement has an error of  $\pm 0.03$  eV. The ionization potential values are given in Table 1 above.

As understood by those skilled in the art, additional substitution, variation among substituents, and alternative methods of synthesis and use may be practiced within the scope and intent of the present disclosure of the invention. The embodiments above are



intended to be illustrative and not limiting. Additional embodiments are within the claims. Although the present invention has been described with reference to particular embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

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